

## THE CHALLENGE OF BONDING TREATED WOOD

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### SUMMARY

Wood products are quite durable if exposure to moisture is minimized; however, most uses of wood involve considerable exposure to moisture. To preserve the wood, chemicals are used to minimize moisture pickup, to prevent insect attack, and/or to resist microbial growth. The chemicals used as preservatives can interfere with adhesive bonds to wood. Given the many potential modes of failures and of interference with bond formation by treatment chemicals, a way to systematically analyze the problem is needed. With the use of several tests, the source of the problem can be generally identified; this information allows the adhesive supplier to understand how to systematically adjust the adhesive formulation to improve bond strength. This is important because new wood-protection chemicals continue to be developed to overcome the limitations of existing treatment chemicals.

### INTRODUCTION

Wood bonding has been very challenging given the great differences in cellular structure and chemical composition among species, and the many different bonding processes used in the assembly of wood products (RIVER et al. 1991, MARRA 1992). The challenge becomes even greater when the wood substrate has been treated with chemicals to improve its resistance to biodeterioration (IBACH 1999). The list of treatment chemicals continues to grow as more effective treatments are developed or as traditional treatments, such as creosote, pentachlorophenol, and chromated copper arsenate (CCA), are replaced in response to environmental concerns. The important question with new wood treatment chemicals is whether they will interfere with wood bonding. The simplest answer, based upon past experience with treated wood, is that they are likely to make bonding more difficult (VICK et al. 1990). Although wood would seem like an ideal substrate for bonding because of its surface roughness, large surface voids for mechanical interlock, and polar cellulosic components for chemical bonds, forming durable bonds to wood can be hard. For wood used under dry conditions, many adhesives can form good bonds, but for wood subjected to water soaking, obtaining durable bonds has been difficult.

Given the complexities of wood species, treatment chemicals, adhesives, and bonding processes, one may wonder about systematic solutions to the poor performance of bonded products. With all this complexity, how can poor bond performance be addressed? The analysis model presented here has been deliberately kept simple to facilitate understanding of the process. However, other factors may need to be considered in specific cases.

## MATERIALS AND METHODS

### Bonding and Debonding Methods

In general, many countries have standard methods for bonding and debonding of wood with adhesives (RIVER et al. 1991). Controlling the bondline thickness can be difficult with wood, e.g., over-penetration can reduce bond strength and decrease wood failure.

### Analysis of Failure Location and Cause

ASTM D 526699 (percentage of wood failure) has been the standard method for determining the location of failure. The problem with this method is the difficulty of estimating areas of failure visually and distinguishing between adhesive and wood failure. Training, using higher magnification and staining techniques, can improve failure estimates and add information about where the bonds are failing. Infrared spectroscopy, scanning electron microscopy, and x-ray photoelectron spectroscopy provide additional information on failure location, as long as the analysis areas are representative. To understand treated wood–adhesive interactions, retardation or acceleration of cure can be determined by exotherm temperature and heat generated during cure using the differential scanning calorimetry (DSC). The gel point indicates cure rate and other modes of viscosity increase that alter penetration.

## RESULTS AND DISCUSSION

An acceptable adhesive is when the failure is located in the bulk wood (Figure 1); this is more likely to occur with a weak wood than with a stronger wood. Bulk adhesive failure is more likely with a thermoplastic than a thermoset adhesive. The interphase region that stretches from the bulk wood to the bulk adhesive can be divided into the adhesive interphase, adhesive–wood interface, and wood interphase. Interphase failure is more common than true interface failure, even though failure is often attributed to interfacial failure without determining the true location of failure. The irregularity of wood surfaces can make the normal location of bond failure difficult to determine.

Wood kept under dry conditions and free from insects can last for centuries, but most wood products are subjected to varying moisture conditions. Although many chemicals and processes have been developed to preserve wood, most of these are known to alter the bondability of the wood (VICK et al. 1990). How can information on good and poor bonds be analyzed to develop an understanding of how the adhesive and treated wood interact?

While there is no general model for how to overcome these problems, understanding the steps of bond formation and failure can lead to improved adhesives for bonding treated wood. The easiest way to think of bond strength is to think of a bond as links in a chain, with the weakest link serving as the failure point (MARRA 1983). However, it is important to try to identify failure within the interphase region in detail to understand the weakest link.

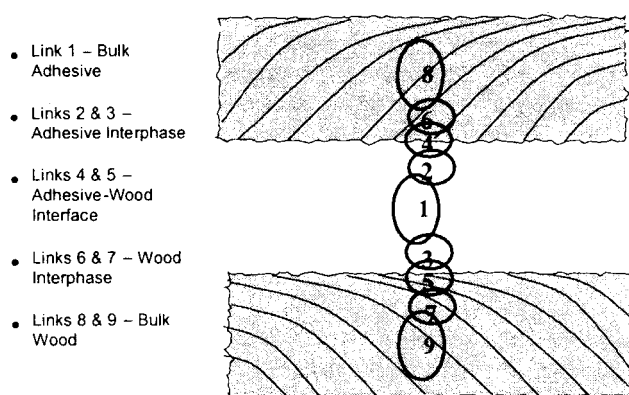


Figure 1: Bond strength can be represented as links in a chain, with failure by determined by the weak link.

Failure within the wood is desirable for determining that the adhesive is performing satisfactorily. For most adhesive bonds, this is the mode observed under dry conditions. However, exposure to water applies additional internal forces upon the bondline as a result of the differential expansion and contraction of wood compared to that of most adhesives (FRIHART 2004). Wood failure is distinguished as deep or shallow in ASTM D 5266; deep failure is more desirable than shallow failure. Some wood treatment chemicals can degrade wood over time, creating premature wood failure (LEBOW and WINANDY 1999). This type of failure is not always observed with standard accelerated tests, and products that passed normal tests without possessing true long-term durability have reached the market. Thus, treatment chemicals need to be evaluated for their ability to weaken the wood or adhesive over time.

The wood interphase can be very dependent on penetration of the adhesive for the formation of full bond strength. The wood treatment can alter adhesive penetration by reducing the surface energy of the wood, by accelerating the cure of the adhesive, and by increasing the viscosity of the adhesive. Most wood adhesives are water based; thus, they need high wood surface energies to be able to wet and penetrate the wood. Many treatments tend to reduce the water adsorption of the wood, which is good for decay resistance. However, if the adhesive is slow to wet the wood, the cure of the adhesive may need to be slowed to allow good penetration. Curing before the adhesive has time to flow into the capillaries can lead to a weak wood interphase and, therefore, a weak link in the chain. In some cases, the reaction of adhesives with treatment chemicals can increase the viscosity of the adhesive. Several studies have shown that borates interact with phenol-formaldehyde adhesives to diminish their bond strength (VICK et al. 1990). The use of polyethylene glycol has been shown to solve the rapid gelation problem by competing with phenol groups for chelating with borate (LEE et al. 2001). The problem of interference with the adhesive occurs with certain forms of borates, namely boric acid and sodium tetraborate octahydrate that chelate, but not with zinc borate.

Interfacial failure is often stated to be the main failure location without much supporting evidence, but there are cases where it most certainly is an important factor. The

chemically weak boundary layer has been placed in this classification because it is not clear whether the real cause of failure is a chemically weak layer or the inability of the adhesive to wet the wood surface, which weakens the bond. Bonding to creosote-treated wood can be a problem if the surface is oily. Bonding to CCA-treated wood has been attributed to the inability of the adhesive to wet the wood surface because of CCA deposits (VICK and KUSTER 1992). This conclusion has been confounded by later data that showed that southern yellow pine with the lowest level of incorporation provided less bond strength than did red pine, white spruce, balsam fir, and jack pine, which had higher levels of CCA adsorption (WANG et al. 2001). The surface of CCA-treated wood is less polar and harder to wet than that of untreated wood (MALDAS and KAMDEM 1998).

An adhesive interphase can be weakened by a treatment that interferes with the cure of the adhesive. Many wood adhesives are low molecular weight polymers that need to polymerize further and develop crosslinks to develop good strength. Wood treatment chemicals can be absorbed by the adhesive and interfere with the cure. For cures that occur under basic or acidic conditions, additives can neutralize the adhesive in the interphase region and alter the cure.

Bulk adhesive properties are less likely than the adhesive interphase region to be affected by treatment chemicals. The adhesive needs to be stronger than the wood to maintain wood failure. Most woods become weaker when they absorb moisture (GREEN et al. 1999); thus, if the treatment reduces moisture pickup, the wood may maintain its strength more than does the adhesive, causing bondline failure.

The analysis in Figure 2 breaks down the location of failure into four zones (wood interphase, interface, adhesive interphase, and adhesive bulk) and lists causes of failure in each zone. The difficulty in applying this analysis is twofold. The first is that it is often very difficult to determine if the bondline failure is primarily within the adhesive interphase, the interface, or the wood interphase because of the lack of discrete layers due to the roughness of the wood surface. The correct determination requires using a combination of methods including both spectroscopy and microscopy as has been done for epoxy failures (FRIHART 2003). The combination of infrared and x-ray photoelectron spectroscopy with light, fluorescence, and scanning electron microscopy can enhance the understanding of the failure location. The second is determining the cause of the failure. Understanding the cause of failure may involve using fracture mechanics, differential scanning calorimetry, dynamic mechanical analysis, or gel times, or combinations of these.

## CONCLUSIONS

Wood can form very durable bonds with the proper adhesive and a fresh bonding surface. Prior studies have indicated that treating wood to enhance its durability has often come at the expense of good bonds for a variety of reasons. Over the years, new treatment chemicals for wood preservation have come into the market to replace those that have become of environmental concern. Can a better understanding of the cause of failure allow for developing improved adhesives in a systematic fashion?

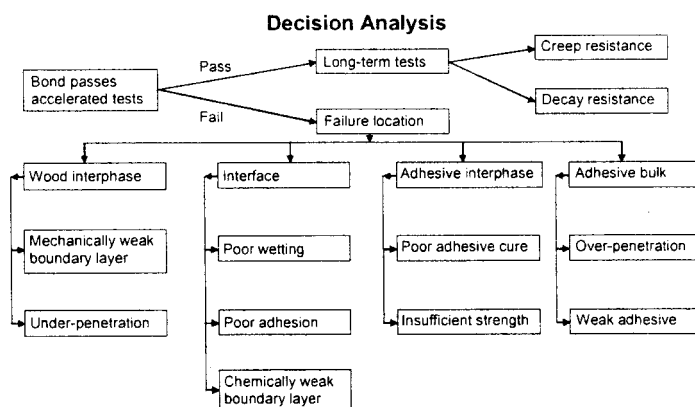


Figure 2: Bond durability is first tested using accelerated tests. If failure occurs, then the location and cause of the failure need to be determined.

A good way to visualize bond failure is to divide the location of failure into nine links on a chain representing the bulk, interphase, and interface links. Failure in each link can be assigned to a specific cause. An improved adhesive can then be developed by understanding what aspect of the adhesive needs to be changed. Some work has been done to better identify the location and cause of failure, but much more work needs to be done for developing proper methods for this analysis.

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